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1 INTRODUCTION

The knowledge represented in an ontology can be regarded as merely a perception from a particular perspective – whether it be that of the modeler or of an autonomous agent. Such interpretation is inline with the representation of ontological knowledge in a context, which is often regarded as a subtheory about the world for a particular situation. Our primary interest is to automatically evolve ontologies by diagnosing and repairing ontological faults, so we will describe a preliminary investigation into the detection of conflicts between ontologies by means of analysing relations between contexts. The presentation of the analysis is based on an example of a physics paradox, caused by a contradiction between the predictive theory and sensory data.

Suppose a bouncy ball B is suspended at a height above ground and a student, who believes that the total energy (TE) of an object is always defined as the summation of only the kinetic energy (KE) and potential energy (PE), is to predict TE of the ball when it impacts with the ground. Sensory data shows that there is a moment in time when the ball makes impact with the ground, both the velocity and the height can be deduced to be zero. This causes a contradiction because the TE at the end of the drop, $TE(B, End(Drop))$, calculated using the sensory data is zero, whereas the prediction is positive by the law of energy conservation. The paradox arises from the (wrong) idealisation of the ball as a particle without elasticity, so the contribution of elastic energy to TE is neglected. This is the *bouncing-ball paradox*.

A natural representation of the paradox is to encode the predictive theory in one ontology (O_t) and the sensory data in another (O_s), letting each be a separate ontology and be locally consistent. The theoretical ontology contains the relevant physics laws, including the theoretical definitions of TE, KE, PE, etc. To give an accurate representation of O_s, in contrast, is to not assert the values of final velocity and height, but to assert the values from the raw data. In essence, the student's calculations of final velocity and height are based on the raw data collected from the experiment and are, therefore, deduced. However, physics laws and relevant definitions are defined in terms of basic properties such as velocities and heights and do not not directly refer to specific attributes of an experiment. Thus, it is essential to bridge this gap, created by the heterogeneity of signatures, so that the relevant terms are properly related across the ontologies.

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2 HETEROGENEOUS SIGNATURES

Requiring O_t and O_s to share a set of signature elements and contain relevant definitions can avoid numerous problems associated with the reasoning and the representation, but at the cost of decreased accuracy and generality. For more accurate and flexible representations, we handle the case in which the ontologies do not share a common signature. Let O_t contain the law of energy conservation, relevant definitions, and claims about the initial state of the ball:

$$\begin{aligned}
&Ax(\mathcal{T}(O_t)) ::= \{\ \forall p{:}Part, t_i, t_j{:}Mom. TE(p, t_i) = TE(p, t_j),\\
&\forall p{:}Part, t{:}Mom.\ TE(p, t) = KE(p, t) + PE(p, t),\\
&\forall p{:}Part, t{:}Mom.\ KE(p, t) ::= \frac{Mass(p, t).\,Vel(p, t)^2}{2},\\
&\forall p{:}Part, t{:}Mom.\ PE(p, t) ::= Mass(p, t).G.Height(p, t)\ \}
\end{aligned}$$

$$\begin{aligned}
&Ax(\mathcal{A}(O_t)) ::= \{\ Vel(B, Start(Drop)) = 0,\\
&Height(B, Start(Drop)) > 0,\ \ldots\ \} \cup Ax(\mathcal{T}(O_t))
\end{aligned}$$

where $Ax(\mathcal{T}(O))$ and $Ax(\mathcal{A}(O))$ denote the axioms of the TBox and ABox of the ontology O, respectively. We adopt DL's distinction between TBox and ABox even though we work with HOL. As will be explained later, this distinction provides several technical benefits. As with O_s, we shall augment the background story of the paradox by assuming that the experiment involves only shooting a series of high-speed photos of the ball while it drops:

$$\begin{aligned}
&Ax(\mathcal{A}(O_s)) ::= \{\ Posn(B, Photo(B, End(Drop) - \Delta)) = 0,\\
&Posn(B, Photo(B, End(Drop))) = 0,\ \ldots\ \}
\end{aligned}$$

where $Posn(B, Photo) = p$ means that the position of the ball B in the photograph $Photo$ is at position p. In the current setting, we can assume $Posn$ to return the 1-D position according to a fixed reference, e.g., a vertical ruler; $Photo(O, T)$ returns the photo of object O taken at time T.

The above configuration requires a significantly different approach for conflict diagnosis because the knowledge represented in O_t and O_s is insufficient to relate the terms in O_t to $Posn$ in O_s. Such asymmetry renders the derivation of a contradiction impossible, but may be tackled, e.g., by using McCarthy's notion of *lifting axioms* described in his work on the formalisation of contexts [3] and in Guha's work on microtheories [2].

2.1 Lifting Axioms

Lifting axioms are rules that help bridge across individual contexts, enabling terms from one context to be translated into another. Using McCarthy's syntax, we may need another ontology, O_b, containing information about relationships between the terms in $\mathcal{T}(O_t)$ and those in O_s in order to bridge across them. Even O_b connects together O_t and O_s, an inconsistency is avoided because the value assertions in the ABoxes are not included in O_b, which eliminates the potential problem of merging conflicting value assertions. For the described O_t and O_s, the axioms of $\mathcal{T}(O_b)$ can be:

$$Ax(\mathcal{T}(O_b)) ::= \{\ \forall p{:}Part, t{:}Mom.\ O_t.Vel(p,t) = \tag{1}$$
$$(O_s.Posn(p, Photo(p, t-\Delta)) - O_s.Posn(p, Photo(p,t)))/$$
$$(t-(t-\Delta)),$$
$$\forall p{:}Part, t{:}Mom.\ O_t.Height(p,t) = O_s.Posn(p,t), \tag{2}$$
$$\forall p{:}Part, t_i, t_j{:}Mom.\ O_t.TE(p,t_i) = O_t.TE(p,t_j),\ \ldots\ \} \tag{3}$$

The term $c.p$ is our shorthand for McCarthy's term $value(c,p)$, which designates the value of the term p in a context (in our case, an ontology) c. Thus, (1) expresses that the value of $Vel(p,t)$ in O_t is equal to the difference between the positions returned by $Posn$ in O_s given two photos, each taken at the beginning and the end of the corresponding interval, divided by the length of the interval. Similarly, (2) means that the value of $Height(p,t)$ in O_t is the same as the value of $Posn(p,t)$ in O_s.

As one would expect, lifting axioms can also be used to relate terms in the simple setup of ontologies that share the same signature. For example, if O_s shares the same signature as O_t and has a theory over the domain containing only B and $End(Drop)$:

$$Ax(\mathcal{T}(O_s)) ::= \{\ TE(B, End(Drop)) =$$
$$KE(B, End(Drop)) + PE(B, End(Drop)),\ \ldots\ \}$$

The corresponding O_b will not contain (1) or (2), but contain the following additional lifting axioms:

$$Ax(\mathcal{T}(O_b)) ::= \{\ O_t.TE(B, End(Drop)) =$$
$$O_s.TE(B, End(Drop)),\ \ldots\ \}$$

3 CONFLICT DETECTION

We adopt a similar approach to detecting a conflict between ontologies represented using contexts as that described in [1], i.e. logically derive formulae from the ontologies that imply a derivable contradiction. Since the representation of ontologies as contexts is more complex than that using object-level logic, care is required to reason with both the meta- and object-levels. Before deriving the trigger formulae from the ontologies, each axiom in O_t and O_s need to be syntactically modified by renaming every term in O_t and O_s, so that the end results are guaranteed to not share any part of the signature. Consequently, O_b is modified accordingly as it specifies the relationships between the terms in the working ontologies. The purpose of the renaming is to avoid an inconsistency from arising when parts of the ontologies are merged, which will be later described. For some ontology O_i, the axioms of the renamed ontology ${O_i}'$ are:

$$Ax({O_i}') ::= \{\phi\{tm^i/tm\}\} \mid \phi \in Ax(O_i), tm \in \phi\}$$

where $\phi\{tm^i/tm\}$ denotes that occurrences of term tm in the formula ϕ are renamed to tm^i; $tm \in \phi$ means that tm is a term in the formula ϕ. The resulting ${O_t}'$, ${O_s}'$, and ${O_b}'$ for O_t, O_s, and O_b, respectively, are therefore:

$$Ax(\mathcal{T}(O_t')) ::= \{\ \forall p{:}Part, t_i, t_j{:}Mom. TE^t(p,t_i) = TE^t(p,t_j),$$
$$\forall p{:}Part, t{:}Mom.\ TE^t(p,t) = KE^t(p,t) + PE^t(p,t),\ \ldots\}$$

$$Ax(\mathcal{A}(O_s')) ::= \{\ Posn^s(B, Photo^s(B, End^s(Drop) - \Delta)) = 0,$$
$$Posn^s(B, Photo^s(B, End^s(Drop))) = 0\ \}$$

$$Ax(O_b') ::= \{\ \forall p{:}Part, t{:}Mom.\ O_t.Vel^t(p,t) =$$
$$(O_s.Posn^s(p, Photo^s(p, t-\Delta)) - O_s.Posn^s(p, Photo^s(p,t)))/$$
$$(t-(t-\Delta)),\ \ldots\}$$

For the sake of symmetry, terms in both O_t and O_s are renamed.

Based on the trigger formulae designed for WMS [1], a conflict between O_t and O_s through lifting axioms is detected if at least two of the following three are matched:

$$O_t \vdash stuff(\vec{s}) = v_1 \tag{4}$$
$$O_s \vdash stuff(\vec{s}) = v_2 \tag{5}$$
$$O_b' \vdash o.stuff(\vec{s}) = \psi,\ Th(\{decntxt(o.stuff(\vec{s}) = \psi)\} \cup \tag{6}$$
$$Ax(\mathcal{A}(O_t')) \cup Ax(\mathcal{A}(O_s'))) \vdash stuff(\vec{s}) = v_b$$

where $O_b' \vdash o.stuff(\vec{s}) = \psi$ means that the term $stuff(\vec{s})$ in ontology o can be expressed as ψ in O_b; $decntxt(\phi)$ decontextualises the formula ϕ such that every term in ϕ is considered to reside in the same context, i.e. $decntxt(o_1.f = o_2.g)$ gives $f = g$. With WMS, conflict is detected if only (4) and (5) are matched and that $O_t \vdash v_1 \neq v_2$. The coverage of this trigger is somewhat limited because, for example, $stuff(B, End(Drop)) = v$ cannot be deduced in O_s alone if $stuff$ is not in the signature of O_s. The WMS trigger formulae can be augmented with (6), such that any two of (4), (5), and (6), and that $O_t \vdash v_1 \neq v_2$ $(\neq v_b)$, depending on the matching formulae, can trigger repair. Note that the resulting merge of the two ABoxes in (6) is guaranteed to be consistent as O_t and O_s no longer potentially share common signature elements, due to the renaming by $\{tm^t/tm|tm \in \phi\}$ and $\{tm^s/tm|tm \in \phi\}$ to every term in each respective ontology.

A conflict can be detected in the bouncing-ball paradox represented using the lifting axioms in (1) and onwards: (4) and (6) can be matched by the substitution $\{stuff/TE^t, \vec{s}/\langle B, End(Drop)\rangle,\ o/O_t,\ v_1/x.\ x > 0,\ v_b/0\}$ and substituting ψ for the sum of KE and PE, expressed in respect to the terms in O_s:

$$0.5\ .\ Mass^s(B, End^s(Drop)).((Posn^s(B, Photo^s(B,$$
$$End^s(Drop) - \Delta)) - Posn^s(B, Photo^s(B, End^s(Drop))))/$$
$$(End^s(Drop) - (End^s(Drop) - \Delta)))^2 + \ldots$$

Clearly, the complexity of the detection mechanism presented is significantly higher than that presented in [1]. One obvious challenge is to reason with knowledge in both meta- and object-levels, i.e. that in O_b and O_t and/or O_s. That said, detecting ontological conflicts as contextual ones enables higher generality, thus accuracy, in the modelling and representation.

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REFERENCES

[1] A. Bundy and M. Chan. Towards ontology evolution in physics. In W. Hodges, editor, *Procs. Wollic 2008*. LNCS, Springer-Verlag, July 2008.

[2] Ramanathan Guha. *Contexts: a formalization and some applications*. PhD thesis, Stanford, CA, USA, 1992.

[3] J. McCarthy and S. Buvac. Formalizing context (expanded notes). *Computing natural language*, 81:13–50, 1998.